Earth Observation-Based Analysis And Modelling Of Coastline Erosion And Accretion Along The Parts Of The East Coast Of India

Rasmoni Karak[1], Shailja Mamgain[2], P. G. Dhar Chakrabarti[1], Arijit Roy[2],
rasmonikarak0@gmail.com, Shailja309@gmail.com, pgdchakrabarti@gmail.com, arijit@iirs.gov.in

1. School of Environment and Disaster Management, Ramakrishna Mission Vivekananda Educational and Research Institute, Kolkata 700103, West Bengal, India
2. Indian Institute of Remote Sensing, Indian Space Research Organisation, Dehradun, India.

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Abstract:

This study examines the patterns and processes of coastal erosion and accretion along the West Bengal coast of India from 1990 to 2020, a region characterized by its dynamic geomorphology and significant socio-economic importance. The West Bengal coast, stretches approximately 157.5 km parallel to latitude along the northern Bay of Bengal, Over the past three decades, this region has experienced considerable changes. To assess the coastal changes, a multi-temporal analysis was conducted using satellite imagery from Landsat images, supplemented by Geospatial techniques, and GIS, which were employed to map and quantify the rates of erosion and accretion. Shoreline positions were delineated at decadal intervals, and changes were analyzed using the Digital Shoreline Analysis System (DSAS) to calculate erosion and accretion rates. The analysis revealed significant spatial and temporal variability in coastal erosion and accretion along the West Bengal coast. The South 24 Parganas is combined with multiple islands and the mainland. We have only considered the specific coastal islands and coastal locations where the historical shorelines were extracted. Ghoramara Islands, Sagar Islands, Jambaudwip Islands, and other islands are taken into four divisions. The East Medinipur district is divided into six divisions and Nayachar Island was also calculated separately. The total erosion of the study area is 2.62 km per year in 30 years and the total accretion of the study area is 1.18 km per year. In 1990 the length of the entire study area was 51.16 km and in 2000 the shoreline length was 52.72 km and the length of the shoreline in 2010 was 50.68 km lastly in 2020 the shoreline length of the study area was 45.51 km. It is the entire study area facing erosion rather than accretion. The study highlights the geographical areas where erosion and accretion take place.

1. INTRODUCTION

To know about coastal erosion and accretion, it is important to identify the actual meaning of the coast and its basic characteristics and major influential components. The coastline is what separates the water and shore on the other side the line that separates the shore and land is called the shoreline. Coast or coastal zones refer to the narrow transition areas that connect terrestrial and marine environments and are the most productive and valued ecosystem of our planet (Crossland, et al., 2005). “Coastal erosion is a result of human activities and natural environmental changes making the coastal dynamic action (wave, current, wind) lose balance in the coast process and long-term loss of sediments of coastal zone results in the destruction process of coastline retreat and beach erosion.” (Huang, et al, 2022). Transgression is different from coastal erosion but also known as sea forwarding due to the relative long-term sea level rise huge landward movement of coastline can be seen (Huang, et al, 2018). On the other side, Coastal accretion is “the gradual increase in the area of land as a result of sedimentation” and further describes Erosion as “the group of loosened or dissolved” (Thomas & Goudie, 2009). abrasion, attrition, corrosion, solution, hydraulic pressure, weathering, bioerosion, scour, cliffing, and longshore drift play significant roles in the process and sub-process of erosion and accretion (Marsh, A. 2008).

Coastlines and shorelines mainly influence the erosion and accretion of coast areas as they are often taken as a baseline to evaluate or calculate the eroded and gained area (Baig, et al., 2020). Man-induce activity or human lifestyle to live in accordance with nature play a significant role in the changes of coastal morphological dynamics same as on natural parameters such as breaching and over-wash, aeolian transport of the dunes, offshore sand loss to canyons, offshore transport at the tip of a sand spit, erosion downstream of accumulative forms, sand loss as coastal protrusions, climate change impacts (Mangor, et al.,2004).

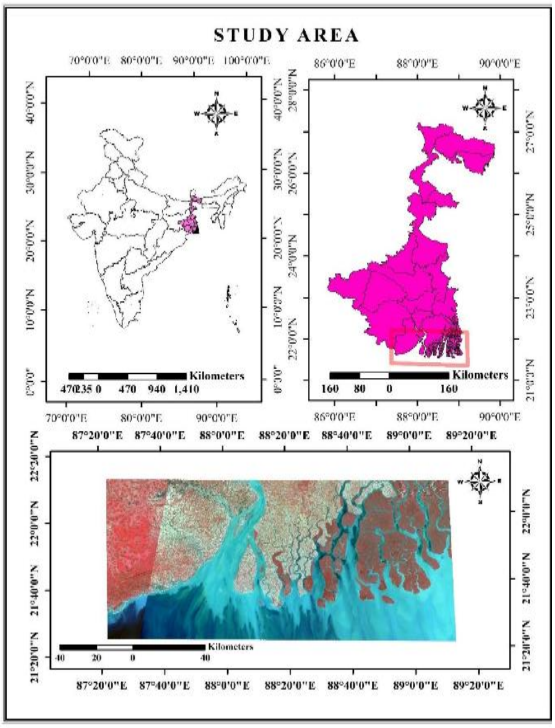

Figure 1. Study Area.

The coastal erosion and accretion in West Bengal coastal districts are dynamic and the conspicuous sedimentation deposition and erosion rate at the mouth of the Hooghly River basin which is the lower tributary of Ganga in the lower plane located in India. Muriganga, Saptamukhi, Thakuran, Matla. Bhangaduani, Gosaba, Harinbhanga these seven revivers, and the Bay of Bengal Ocean are mainly dominating the major changes in the coastal areas of South 24 Parganas islands. This study wants to find out the coastal erosion and accretion rate from 1990 to 2020 of East Medinipur, South 24 Parganas, and North 24 Parganas through the use of remote sensing and GIS technology. 1) Shoreline extraction using long-term satellite data. 2) Identify the net change of land loss and gain in the study area. 3) Prediction of the potential shoreline in the next 20 years. 4) Based on hotspots of eroded and accreted areas, propose potential mitigation strategies for sustainable coastal development.

2. Materials and Method

To calculate coastline erosion and accretion, the study collected some data, Landsat TM (Thematic Mapper) and OLI (Operational Land Imager) from USGS Earth Explorer of 1990, 200, 2010, and 2020. For comparison with recent shoreline 2024 data was also downloaded. To create a historical record of shoreline positions shoreline data from different years (1990, 200, 2010, and 2020) are digitized. This involves the use of specialized software to accurately delineate the shoreline from satellite images. ArcGIS 10.8 version used to execute the whole Process.

Satellite and Sensor	Year	Spatial Resolution (m)	Path & Row
Landsat-5 TM	1990	30	P-138, R-045
Landsat-5 TM	2000	30	P-138, R-045
Landsat-5 TM	2010	30	P-138, R-045
Landsat-8 OLI	2020	30	P-138, R-045
Landsat-8 OLI	2024	30	P-138, R-045

Table 1. List of Data Used.

ArcGIS is a powerful Geographic Information System (GIS) software. Simultaneously, from the most recent Landsat-8 OLI imagery, specifically from the year 2024 the baseline is extracted. Here the baseline or recent year shoreline serves as a reference line from which change rate of historic years shoreline can be measured In ArcGIS, the Digital Shoreline Analysis System (DSAS) Model version 5 facilitates the analysis. Within the DSAS model, the working process starts with the default Attribute Automator next, have to set the default parameters of baseline, shoreline, and metadata settings. Now transects can be generated, so after adjusting all the parameters and rechecking afterwards, transects were generated at regular intervals. These transects help to measure the distance between the baseline and the shoreline at different transect points in a selective time frame as the transects were extended to the digitized shorelines of previous years. After the generation of transect, several statistical methods are employed to analyze the change in shoreline over time Shoreline change Envelop (SCE), Net Shoreline Movement (NSM), NSM values present the distance between the oldest and the youngest shoreline that intersects in the transects and values are in meters.

NSM= (Oldest bankline - Youngest bankline).

End Point Rate (EPR),

The EPR rate is calculated by dividing the distance of shoreline movement throughout the time elapsed between the oldest and the most recent shoreline. The unit of value is represented in meters/year.

$EPR = \{(N_{OB} - N_{YB}) / (M_{OB} - M_{YB})\}$

Where, $(N_{OB} - N_{YB})$ is the distance between the oldest bankline (N_{OB}) and the Youngest bankline (N_{YB}). $(M_{OB} - M_{YB})$ is the time between the oldest bankline (M_{OB}) and youngest bankline (M_{YB}).

Weighted Linear Regression (WLR) and Linear Regression Rate (LRR). Net Shoreline Movement (NSM), It gives us a numerical value of the location.

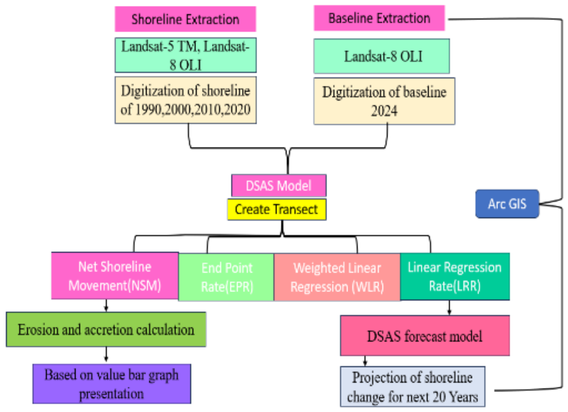

Figure 2. Methodology.

After generating the Shapefiles of shoreline and baseline to marge all the shoreline into one geodatabase file as shoreline and attributes like SHAPE Length, date, and uncertainty should be generated along with the preparing shoreline shapefile, although for baseline geodatabase attributes like SHAPE Length, Id, and group must be created otherwise DSAS will not able to computerized the functional algorithms.

After adding the prepared geodatabase in Arc software DSAS toolbar will be available now, add required and optional fields to one or more selected shorelines and or baseline feature classes which are available in a geodatabase within the Attribute Automator tool. After setting the Attribute Automator tool Set Default Parameters tool will be active here three small windows will be open one window is Baseline Settings in which the three parts are available one part is Baseline Parameters where in baseline layer user have to select the baseline geodatabase which was created in beforehand, in baseline id field attribute of id needed to be selected and in group field attribute group should be selected next in the baseline search distance field attribute group search can be chosen second part is location of Land Relative to Baseline Orientation if click in show baseline orientation then baseline will generate some arrows.

Then to select in which part land area is present, have to choose the box accordingly the baseline placement whether in onshore or offshore or it in midshore or combinational after completing this baseline setting windows then open second shoreline settings window where at shoreline layer select created shoreline geodatabase and in shoreline data field select attribute created named as date and in shoreline uncertainty field use attribute uncertainty and in default data uncertainty -10 - +10 in meter can be kept or can be changed based on calculated uncertainty value then set intersection in seaward or landward after finishing the shoreline setting window go to metadata settings window and some of the general information needed to be fill up like Originator, abstract, purpose, data update and access information, update frequency, progress, what are data current to, constrains on access and some of the contact information like organization, person, address, city, state, zip, phone, email etc., keep in mind all the information needed to be fulfilled. The last part is log file output where the infromation need to choose between regular, extended, or none and then click ok.

After setting the set default parameter now have the cast transect which generates a new transect feature class based on a user-specified setting, in the pop-up box of cast transects have two windows one window is cast transects here in transact storage parameters select the location, and give a name within the select existing or enter new transect name next in casting minimum search distance from baseline, for example, to set the value 1000 for, Ghorama islands and transect spacing value is 1000 and smoothing distance value is 500. Smoothing Distance value length allows users to pan through various examples of smoothing to determine the best option for their shoreline data. Click ok after selecting all the data carefully. By clicking ok software will be minimized and a pop box will appear click ok and open the minimized software and the transect layer will be available.

The lines which are adjoining the baseline and other shorelines are known as transects. If the transects are not well-connected then transects can be edited with the help of the edit option for editing transects select the layer in which to edit in transect layer selection, if it do not select the layer before editing the transect then the DSAS algorithm will not be able to track the changes, so make sure the layer is selected properly before start editing. When the transect which connects all the lines then go for the calculation. Selecting the transects layers in the transect layer section then the calculate rates tool will be active now select the specified boxes for which statistical measure to calculate or select all, this study selected all to calculate and applied the shoreline intersection threshold in 2 and confidence interval kept in 90.0% and select which statistical calculation will be appear in a color ramp in the display. The current study selected the net shoreline movement change rate to display and set the location in the device where to save the file. Then click on calculate when the result is generated click the cancel or exit button. Now the result is in the screen select the layer and click start editing open the attribute table and calculate latitude and longitude with the help of the calculate geometry option after creating new fields, after calculating save the data table in excel. In the same way for the whole study area the transects and the net changes were calculated, by analyzing the whole study area generated data set maximum and minimum values were identified in all divisions of the study area. Here to simplify the study the scale was divided to identify which areas are most prone to changes by dividing the classes into seven classes. These seven classes were classified based on the erosional and actional highest and lowest values.

Color	Values	Zones
	>-1800	High Erosion Zone
	-1800 - -900	Moderate Erosion Zone
	-900 - -1	Erosion Zone
	-0.9 - +0.9	Stable Zone
	1 – 600	Accretion Zone
	600- 1200	Moderate Accretion Zone
	>1200	High Accretion Zone

Table 2. List of Classes.

3. Result and Discussion

Ghoramara Island stands out as the most severely affected by erosion, with no significant accretion observed. The island's maximum negative shoreline change (NSM) of -2606.03 meters and a mean erosion of -313.59 meters categorize it as a high erosion zone, highlighting its vulnerability and the urgent need for intervention to prevent further land loss and potential displacement of its inhabitants. Sagar Island exhibits a more dynamic pattern with both erosion and accretion. While 79.8% of transects are under erosion, the presence of accretion zones, particularly in the southern part, suggests some resilience. The island's mean NSM change of -151.65 meters, with significant maximum values for both erosion and accretion, underscores the complexity of coastal processes at play. In four selective divisions of South 24 Parganas, the four divisions exhibit varying degrees of shoreline changes. The first division is predominantly erosional, with 96.2% of transects facing erosion, marking it as highly vulnerable. The second division shows a more balanced dynamic with 70.7% erosion and 29.3% accretion, suggesting areas where natural sediment deposition might be leveraged for coastal protection. The third (selected locations of Mousuni island Bakkhali which is also known as Henry Island, Lothian Island, G-plot, and Sundarban Danchi Forest) division and fourth division similarly display a mix of erosion and accretion, with the fourth (Bulcherry islands and the islands edges of Sundarban National Park at selective locations) division experiencing the highest maximum shoreline changes for both erosion and accretion, indicating the presence of both high risk and potentially resilient areas.

Jambudwip Island is characterized by significant erosion, particularly in its western part, where all 50 transects exhibit substantial shoreline retreats. The eastern part, while slightly less erosional, still faces considerable challenges, emphasizing the need for targeted erosion control measures to preserve the

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island's integrity. In East Medinipur, the six divisions reveal a spectrum of erosion and accretion dynamics. The first (endpoint of Odisha coast or starting point of west Bengal coast to Champa River) and second divisions (From Champa River to end of Tajpur sea beach) are predominantly erosional. The third division (From Mandarmani Beach to Pichaboni River) shows a minor presence of accretion, which could be optimized through strategic sediment management. The fourth (From Pichaboni River to Rasulpur River), fifth (From Rasulpur River to Haldi River), and sixth divisions (From Haldi River to the mouth of Hooghly River) display a combination of erosion and accretion, with the fourth division having the most substantial accretion potential, indicating areas where natural processes could be harnessed to counteract erosion. Nayachar Island presents a more balanced picture with 55.3% of its transects showing accretion. This significant accretion, with a mean NSM change of 166.22 meters, positions Nayachar as a relatively resilient island in the study area. However, the island also faces substantial erosion, suggesting that even in areas of significant accretion, erosion remains a critical concern. Although the study did not include the erosional and accretional parameters the reason behind the accretion of the East Medinipur division might be the Subarnarekha delta in the west and Hooghly delta in the east part of this district.

The overall trends indicate that the Sundarbans region is predominantly erosional, with Ghoramara Island being the most affected and Nayachar Island demonstrating notable accretion. The high r2 value for erosion (0.6998) indicates a strong correlation between location and erosion rates, while the lower r2 value for deposition (0.2012) suggests that other factors may influence deposition rates.

Using the DSAS Kalman Filter forecast model, the study projects that most areas will continue to face erosion over the next 20 years, with some regions experiencing minor accretion. The generated forecast model has some limitations as it does not include the other influential parameters so the outcome is not accurate it has some uncertainty range which will be influenced further by the other parameters.

Ghoramara: The Ghoramara island has 73 erosional transects out of 73. The mean NSM is -318.97 meters in 30 years. The minimum erosional transect value is -132.61 meters and the maximum erosional transect value is -659.48 meters over the past 3 decades. The mean erosion of the area is -313.59 meters in this island in the past three decades. Transect classes and future prediction of shoreline are represented graphically in Figure 3 and Figure 4 respectively.

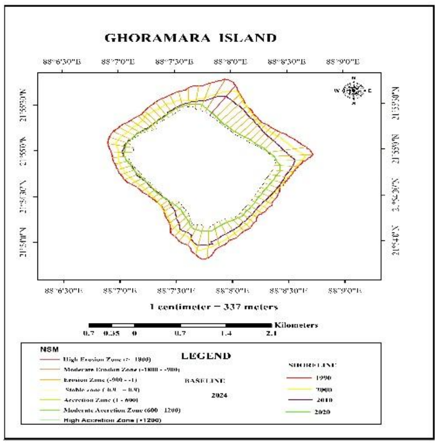

Figure 3. Classes of Erosion and Accretion on Transect.

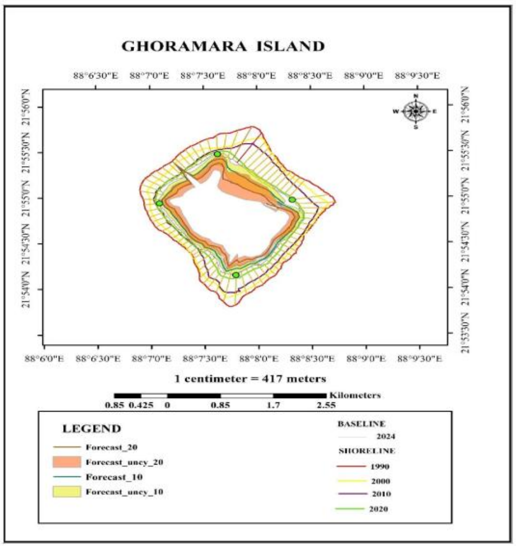

Figure 4. Future Prediction for the next 20 years.

Sagar: 567 transects are under erosion and 144 transects are under accretion out of 710 transects which means 79.8% area is under erosion and 20.2% of the area is under accretion. The mean NSM change is -151.65 meters and maximum accretion value is 1010.19meter and the maximum erosion value is -864.35. The mean erosion of Sagar Island is -198.53 meters and the mean accretion is 46.88 meters. Transect classes and future prediction of shoreline are represented graphically in Figure 5 and Figure 6 respectively.

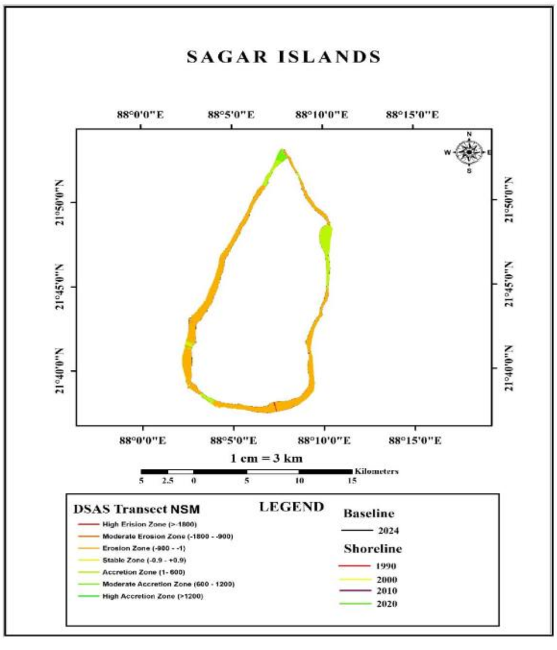

Figure 5. Classes of Erosion and Accretion on Transect.

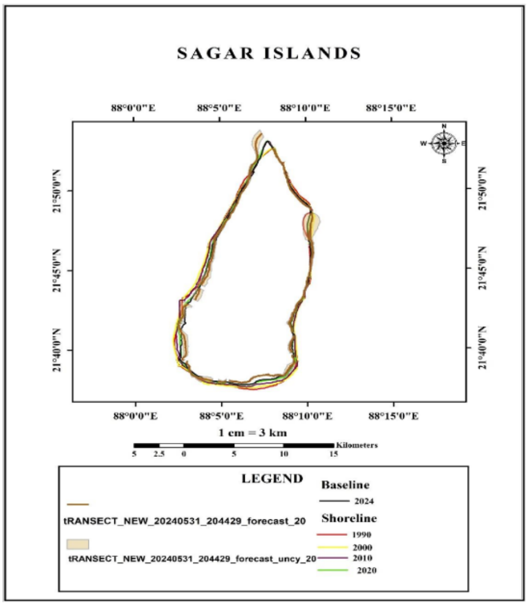

Figure 6. Future Prediction for the next 20 years.

Selected areas of South 24 Parganas: A total of 709 erosional and 134 accretional transects are present out of 842 transects which indicates 84% of transects are facing erosion and only 16% of transects have accretion in the Sundarbans. Mean shoreline changes of the entire selective 4 divisions of Sundarbans. 1695.95 meters maximum accretional shoreline change has been seen and maximum erosional shoreline change is -2606.03 meters in specific transect over 30 years. The mean erosion of the area is -684.59 meters and the mean accretion is 166.92 meters. In divisions two three and four some of the transects have accretion but compared to all mostly erosion takes place. Transect classes are represented graphically in Figure 7,8,9,10 and future predictions of shoreline in Figure 11.

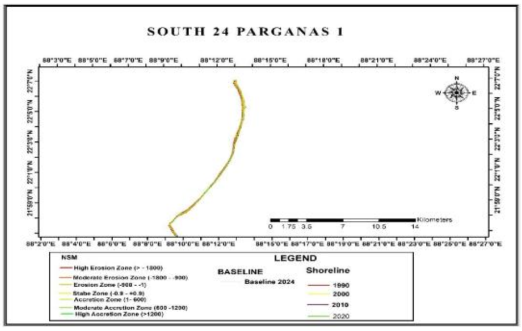

Figure 7. Classes of Erosion and Accretion on Transect.

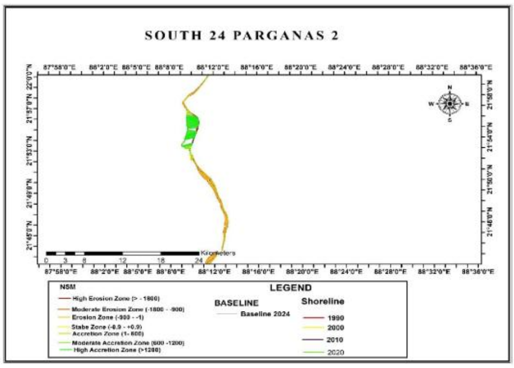

Figure 8. Classes of Erosion and Accretion on Transect.

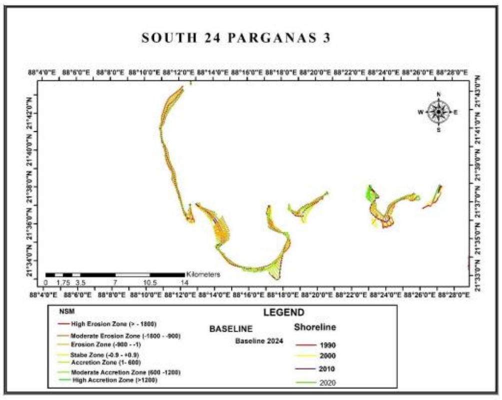

Figure 9. Classes of Erosion and Accretion on Transect.

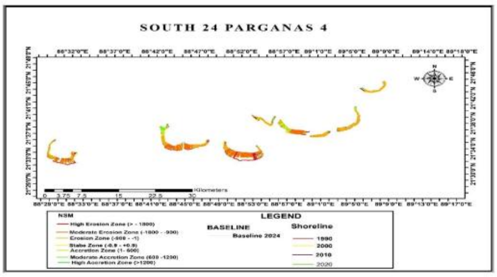

Figure 10. Classes of Erosion and Accretion on Transect.

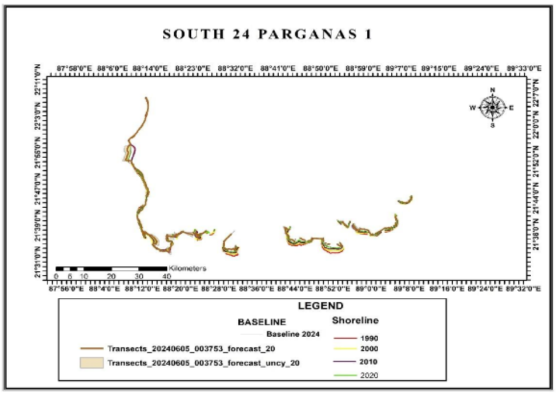

Figure 11. Future Prediction for the next 20 years.

Jambudwip: At the first division or western part of the Jambudwip island mostly erosion takes place along all 50 transact. The mean shoreline change is -1077.79 meters in 30 years. The minimum erosion shoreline change is -501.6 meters and the maximum shoreline change is -2513.43 meters. The mean erosion of the place is -2113.32 meters. 100% erosion takes place in Jambudwip's 1st part. Transect classes and future prediction of shoreline are represented graphically in Figure 12 and Figure 13 respectively.

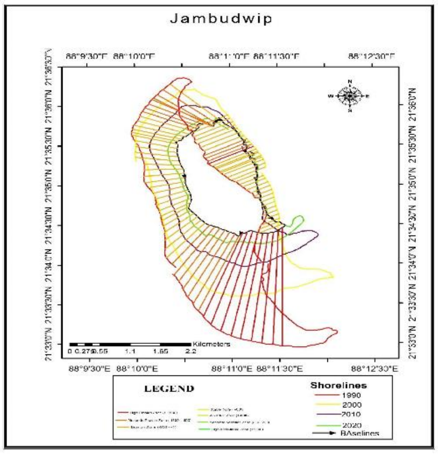

Figure 12. Classes of Erosion and Accretion on Transect.

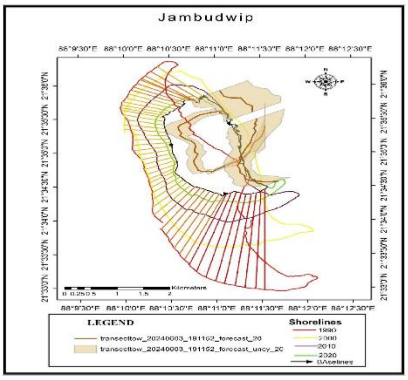

Figure 13. Future Prediction for the next 20 years.

In the second division or eastern part of the Jambudwip Island total 34 transect are their 33 transect out of 34 transects are erosional and only one transect is facing accretion. The mean shoreline change is 483.06 meters and maximum accretional shoreline change is -25.29 meters and the maximum erosion is 912.32 meters. Mean accretion is 0.74 meters and mean erosion is 483.80 meters. This value should be the opposite which means the DSAS algorithm did not catch the shoreline land relative baseline orientation.

East Medinipur: In East Medinipur total of 1087 transects are generated. 821 transects are identified as erosional transects and 266 transects are identified as accretional transects which means 75.5 % area is slowly eroding and 24.5% area is under erosion. The mean NSM is 87.54 meters in the past 3 decades. Maximum accretion is 1115.83 meters and maximum erosion is -1069.55 meters. The mean erosion of the total East Medinipur coast is -157.07 meters and the mean accretion is 69.52 meters. Transect classes are represented graphically in Figure 14,15,16,17,18,19 and future predictions of shoreline in Figure 20.

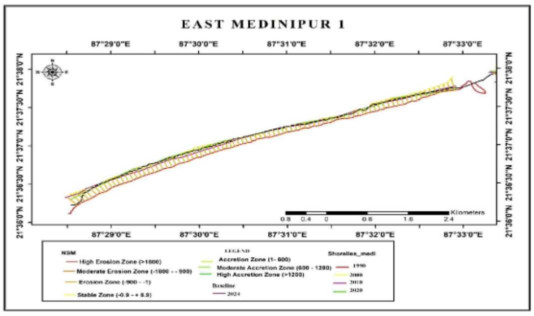

Figure 14. Classes of Erosion and Accretion on Transect.

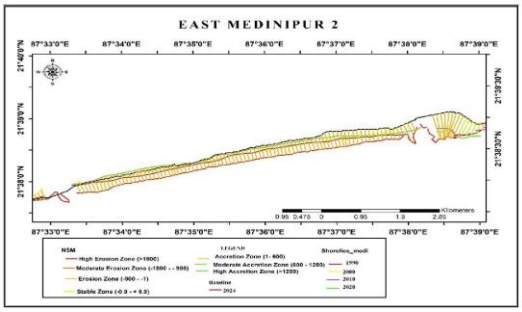

Figure 15. Classes of Erosion and Accretion on Transect.

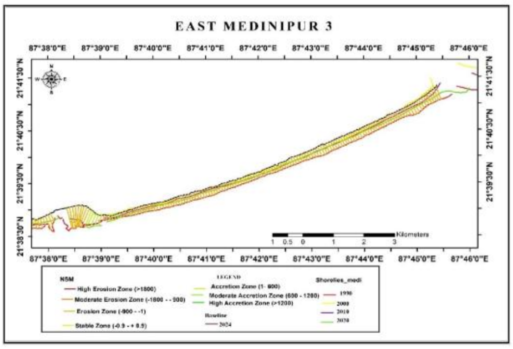

Figure 16. Classes of Erosion and Accretion on Transect.

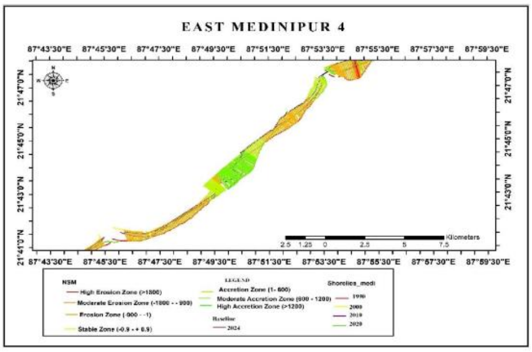

Figure 17. Classes of Erosion and Accretion on Transect.

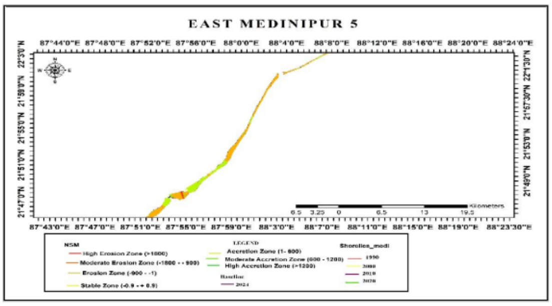

Figure 18. Classes of Erosion and Accretion on Transect.

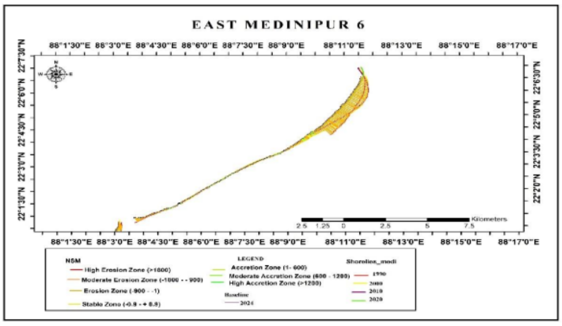

Figure 19. Classes of Erosion and Accretion on Transect.

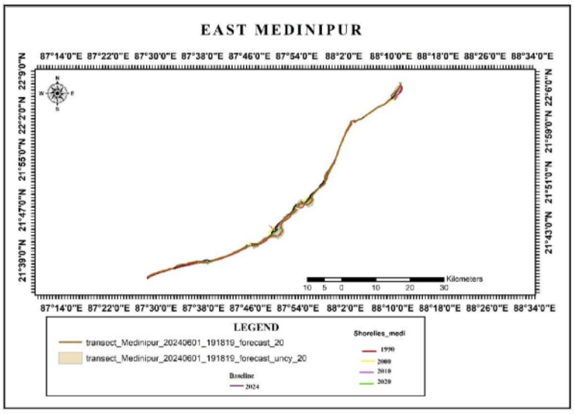

Figure 20. Future Prediction for the next 20 years.

Nayachar: A total of 510 transects were generated 228 transects are facing erosion and 283 transects have accretion which means 44.7% area is under erosion and 55.3% area is under accretion. The mean NSM change is 166.22 meters. Maximum accretion is 1197.06 meters and maximum erosion is -818.12 meters. Mean erosion is -177.84 meters and mean accretion is 344.07 meters. Transect classes and future prediction of shoreline are represented graphically in Figure 21 and Figure 22 respectively.

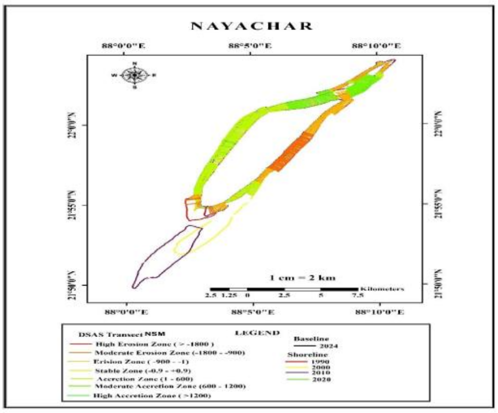

Figure 21. Classes of Erosion and Accretion on Transect.

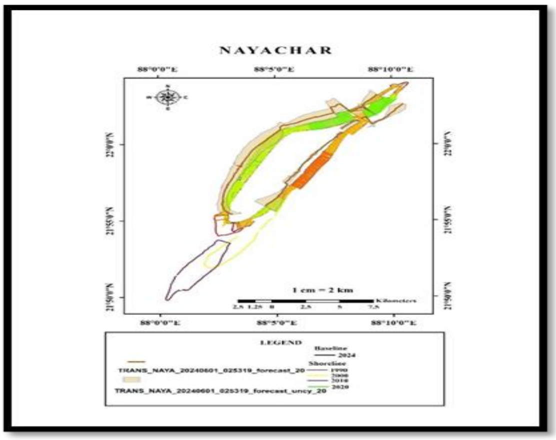

Figure 22. Future Prediction for the next 20 years.

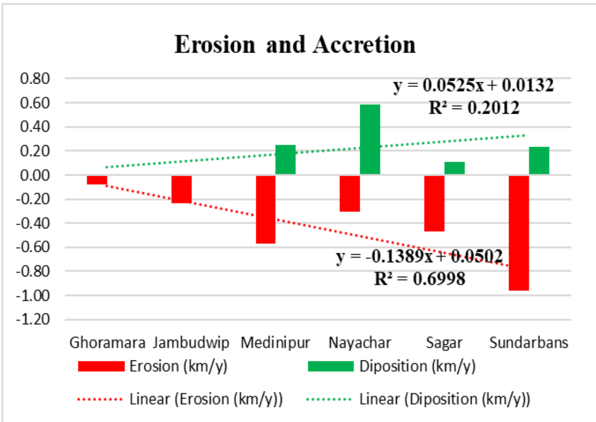

Figure 23. Total Erosion and Accretion.

Locations	Erosion (km/y)	Deposition (km/y)
Ghoramara	-0.08	0.00
Jambudwip	-0.23	0.00
Medinipur	-0.57	0.25
Nayachar	-0.30	0.58
Sagar	-0.47	0.11
Sundarbans	-0.96	0.23
Total	-2.62	1.18
Net landloss or gain	-1.44(km/y)	

Table 3. List of Net Erosion and Accretion.

An erosion r^2 value of 0.6998 signifies that approximately 69.98% of the variability in erosion rates can be explained by the linear regression model. This relatively high r^2 value suggests a strong correlation between the predictor variable of locations and the erosion rates. It implies that the linear trend line is a good fit for the erosion rates based on location. The deposition r^2 value of 0.2012 means that only 20.12% of the variability in deposition rates is explained by the linear regression model. This low r^2 value indicates a weak correlation between location variables and deposition rates. Therefore, the linear trend line is not a good fit for the deposition data, implying that other factors not included in the model might significantly influence deposition rates, or that the relationship between the location and deposition is non-linear or more complex. The r^2 values highlight that the linear model is a better fit for explaining erosion rates compared to deposition rates, suggesting different underlying dynamics or influences on these two processes.

4. Conclusion and Recommendations

The Study is based over the last three decades on various islands and divisions in the selected locations of Sundarbans region and East Medinipur revealing a highly dynamic shoreline with significant changes due to erosion and accretion. By analyzing historical shoreline data and employing statistical calculations, this research identifies areas most prone to changes, classifying them into seven zones - High Erosion, Moderate Erosion, Erosion, Stable, Accretion, Moderate Accretion, and High Accretion. The findings underscore the critical need for tailored coastal management strategies to address the varying degrees of shoreline stability and mitigate the adverse effects of erosion.

Despite having multiple limitations study shows various erosional and accretional transects. Individual transect have their latitude and longitudinal values which enable the visualization of the geographically located erosional and accretional areas. Here this opportunity enables to identify the hotspot of eroding locations and can indicate the potential population density of that particular hotspot eroding location through the Population Density Map along with that if possible then also calculate the agricultural or cropland area that is facing the erosion by conducting Land use and Land change (LULC) map through Remote Sensing then it should be able to detect the areas which need the fastest attention to taking measures and mitigations strategies that will helps to reduce the potential future hazardous risk at the coastal areas. Proactive and adaptive coastal management strategies to mitigate the impacts of erosion, support the resilience of accretion zones, and protect vulnerable coastal communities needed to be identified,

After identifying the hotspot's erosional locations from the Population density map and LULC map combined with this study government or stakeholders can select or identify the exact location that needs to be concretized or other nature-based solutions, which is ecologically considerable as it suggests only concretized those selected eroding location and not concertized whole coastline which is ecologically sensitive so it should not be fully concertized. It also reduces the time for identifying actually which particular areas need immediate attention.

Despite India being the world's third largest economic country it is still in the developing stage. So, the country has various fields to emerge and economic investment is crucial for any developing country. If concretization of coastal areas for only selected hotspot-eroding locations is economically more valuable. Thus, it helps the government, Stakeholders, and Policymakers to make effective decisions to be prepared for reducing the risk of upcoming disasters.

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